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Steel for the production of high-strength components with excellent low-temperature toughness and uses of a steel of this type

The invention relates to a steel for the production of high-strength components with excellent low-temperature toughness. Steels of this type are used, for example, for the manufacture of stop or clamping means, such as are required for fastening and securing loads. These steels are, in particular, processed to form hot-rolled bar steel, rolled wire or bright steel, from which welded round steel chains are then made.

The demands placed on steels of the aforementioned type are set out in DIN 17 115. In addition to good deformability and equally good suitability for welding, the steels have to have excellent strength and toughness properties in order to meet the requirements that are set as a result of the stresses that occur in practice.

The high-grade steels 23 MnNiCrMo 5 3 and 23 MnNiCrMo 54, which are known for this purpose and are specified in DIN 17 115, respectively comprise (in % by weight) 0.20 to 0.26 % C, = 0.25 % Si, 1.10 to 1.40 % Mn, respectively 0.020 % P and S, the sum of the contents of P and S not exceeding 0.035 %, if necessary 0.020 to 0.050 % Al, up to 0.014 % N and 0.40 to 0.60 % Cr. 0.20 to 0.30 % Mo and 0.70 to 0.90 % Ni are also added to the steel 23 MnNiCrMo 5 2, whereas the steel 23 MnNiCrMo 5 4 additionally contains 0.50 to 0.60 % Mo and 0.90 to 1.10 % Ni.

Another steel for the manufacture of chains intended for securing or mooring ships or drilling platforms is known from Chinese patent publication CN-1281906. The Abstract of this

publication, which is available in the WPINDEX database, discloses that the known steel contains (in % by weight) 0.25 to 0.35 % C, 0.15 to 0.30 % Si, 1.45 to 1.75 % Mn, 0.90 to 1.40 % Cr, 1.00 to 1.20 % Ni, 0.45 to 0.65 % Mo, 0.02 to 0.06 % Nb, 0.020 to 0.05 % Al, up to 0.020 % P, up to 0.15 % S, up to 0.20 % Cu, up to 0.03 % Sn, up to 0.01 % Sb, up to 0.04 % As, up to 0.005 % B, up to 0.009 % N, up to 0.0020 % O, up to 0.0002 % H, the remainder being Fe and inevitable impurities, wherein a carbon equivalent also has to be greater than 1.4.

Practical experience has shown that although the known steels meet the requirements set with respect to strength and toughness at ambient temperature, problems arise, especially with regard to toughness, at lower temperatures.

The object of the invention was therefore to provide a high-strength steel that has excellent toughness even at low temperatures, so the risk of the component, which is produced in each case from the steel, breaking is reduced to a minimum even under unfavourable, hard operating conditions. Advantageous uses of this steel are also to be specified.

With regard to the steel, this object is achieved, according to the invention, in that steel according to the invention for the production of high-strength components with excellent low-temperature toughness has the following composition (in % by weight):

C: 0.08 to 0.25 %,
Si: 0.10 to 0.30 %,
Mn: 0.80 to 1.60 %,
P: = 0.020 %,
S: = 0.015 %,

the sum of the P and S content being = 0.030 %,

Cr: 0.40 to 0.80 %,

Mo: 0.30 to 0.50 %,

Ni: 0.70 to 1.20 %,

Al: 0.020 to 0.060 %,

N: 0.007 to 0.018 %,

V: = 0.15 %,

Nb: = 0.07 %,

the sum of the V and Nb content being = 0.020 %, the remainder being iron and inevitable impurities.

In the case of steel according to the invention, the individual alloy components are selected such that a property profile that optimally satisfies the requirements set is achieved. This is achieved by the contents of Cr, Ni and N that are set according to the invention and the minimum sum of the contents of Nb and V. If the content ranges of these alloy elements that are set according to the invention are adhered to, a particularly high toughness, good hardenability, improved retention of hardness when tempering and a particularly fine grain structure are achieved. Steel according to the invention is also highly cold formable and has high strength in the finished processed state. It is also distinguished by high notch impact toughness and a low fracture appearance transition temperature such that brittle fracture occurs only at temperatures that are substantially lower than the brittle fracture temperature of steels known from the prior art.

The C-contents located in the range from 0.08 to 0.25 % by weight ensure the good low-temperature resistance of steels according to the invention. Particularly positive results are produced in this connection if the C content is from 0.16 to 0.23 % by weight.

The good hardenability and retention of hardness when tempering of the steel according to the invention are achieved by means of the limitation of the Cr contents to 0.40 to 0.80 % by weight in combination with Mo contents from 0.30 to 0.50 % by weight. The degree of certainty with which this combined effect is achieved may be increased in that the Cr contents are adjusted to 0.40 to 0.65 % by weight and the Mo contents to 0.35 to 0.50 % by weight.

Ni contents from 0.70 to 1.20 % by weight, in particular 0.75 to 1.00 % by weight, bring about the good low-temperature toughness that is to be emphasised, in particular, in steel according to the invention.

The contents of Al from 0.020 to 0.060 % by weight, in particular 0.020 to 0.045 % by weight, and of N from 0.007 to 0.018 % by weight, in particular 0.007 to 0.015 % by weight, lead in steels according to the invention to a particularly fine grain structure.

Finally, the fact that steel according to the invention contains in total at least 0.02 % by weight Nb and V, while the contents of V are limited to at most 0.15 % by weight and of Nb to at most 0.07 % by weight, ensures that the desired fine grain structure is still maintained even at elevated temperatures. It has surprisingly been found in this connection that this effect occurs particularly reliably if the steel according to the invention is free of vanadium.

According to a preferred configuration, there is therefore no V whatsoever in steel according to the invention, or it is present only as an inevitable impurity.

The fine grain remains stable even in the course of the temper-hardening treatment. Finished processed steel according to the invention therefore commonly has an austenite grain size that is finer than ASTM 10. The fineness of the structure of steel according to the invention is therefore substantially greater than that of known steels, for which an austenite grain size of ASTM 5 is required according to DIN 17 115.

The invention therefore provides a steel that has excellent toughness even at low temperatures. As a result of the favourable combination of its properties, the risk of a component produced from steel according to the invention breaking is reduced to a minimum even under unfavourable, hard operating conditions.

Steel according to the invention is preferably processed to rolled steel. The aim of the processing is to preserve via each of the processing steps the finest possible grain structure of the steel according to the invention. This includes not only the process steps carried out during the heating and rolling, but also the annealing treatments that are carried out before and after the component formation. According to the invention, the heating and rolling conditions are thus selected such that despite the diffusion processes that occur during heating, high rolling temperatures may be avoided, in order to suppress the formation of coarse grain. The temperatures during the further deformation are also selected by means of a controlled withdrawal of energy during the heat deformation such that the desired construction with its fine grain

structure is maintained. An accelerated withdrawal of heat immediately after the final deformation step prevents, in the sense of a "freezing" of the ultimately achieved structure state, undesirable precipitation processes that would otherwise result in a decrease in the hardness and toughness. Instead, by a long-term heat treatment desired precipitation states of the carbonitrides with respect to the size and distribution thereof are produced, in order to obtain the relatively low material strengths of the steel in the hot-rolled state that is desired for cold forming of the steel to form the respective component.

As a result of its particular property spectrum, steel according to the invention is particularly suitable for the production of high-strength components by cold forming with subsequent temper-hardening. These components may, for example, be means for the carrying, pulling, lifting, conveying or securing of loads that are allocated to the highest strength class. Such articles, which may be summarised under the general term "stop and clamping means", include, for example, attachment points, hooks, clips, eyelets, chains, joints, catch elements, rockers, braces, spindle and ratchet clamps, attachment eyes and the like.

Means for the connection of structural elements having excellent use properties may also be made from steel according to the invention. These structural elements are, for example, bolts or other connecting or force transmission elements, such as screws, clamps, rods or the like.

One field of application for which steel according to the invention is particularly suitable is the manufacture of chains. Chains made of steel of the composition according to the invention reliably withstand heavy loads even at very cold temperatures, without any risk of fracture or comparable

damage. Round steel chains, especially welded round steel chains, which are able to satisfy even the most stringent requirements, may thus be made of steel according to the invention.

The components made of steel according to the invention commonly have a strength of at least 1,200 MPa, in particular more than 1,550 MPa, 1,600 MPa or 1,650 MPa. It should be emphasised in this connection that at a strength of at least 1,550 MPa, the fracture appearance transition temperature FATT of the components made of steel according to the invention is commonly at most -60 °C. This limit temperature is significantly lower than in known steels.

It is equally notable that the notch impact working value, in the case of components produced from steel according to the invention, is commonly more than 45 J and the respective component has a technical crack initiation toughness J_{IC} of more than 170 N/mm at -60 °C, in particular more than 185 N/mm. The crack initiation toughness J_{IC} is a value defined in the ASTM 1820 that allows evaluation of the ductile fracture tendency of a steel material.

The high degree of toughness of the steel according to the invention is also discernible in the fact that components produced from steel of this type commonly exhibit an elongation at break of more than 28 %.

The invention will be described below in greater detail with reference to an embodiment.

A steel comprising (in % by weight)

0.19 % C,
0.20 % Si,

1.31 % Mn,
0.005 % P,
0.010 % S,

P content + S content = 0.015 %,

0.45 % Cr,
0.37 % Mo,
0.88 % Ni,
0.400 % Al,
0.008 % N,
0.01 % V,
0.06 % Nb,

(V content + Nb content = 0.07 %),

the remainder being Fe and inevitable impurities,

was melted and processed to form a rolled steel. In order to ensure the finest possible grain structure of the obtained product after the hot rolling, the rolling temperatures were kept at a low level during the hot rolling. Moreover, cooling of the rolled product was carried out between each rolling step, in order to dissipate heat produced by the hot forming itself. Immediately after the hot rolling, the obtained hot-rolled product was quenched in order to freeze the fine grain structure of the steel that is present on leaving the hot rolling path such that it is also reliably preserved in the subsequent processing steps.

After the hot rolling and a long-term heat treatment, which was carried out in order to set a beneficial strength for the subsequent cold forming, the rolled steel was shaped to form chain links, which were closed by welding once the chain had been assembled.

The chains produced in this manner exhibited a fine grain structure of ASTM 11, a strength of 1,270 N/mm^2 and a fracture appearance transition temperature FATT determined at this strength of -70 °C. Their notch impact working value was 557 J at -60 °C test temperature and the elongation at break was 28 %.

In the accompanying diagram, the course of the ductile fracture value J integral for steel according to the invention is plotted over the crack expansion REW at a temperature of -60 °C for a standardised initial crack length a/w of 0.4. It may be seen that there is a crack initiation toughness J_{IC} of 185 N/mm^2 at the technically relevant start of the stable crack expansion.